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A Demonstrated Approach for Improving Performance and Reliability of Biological Wastewater Treatment Plants

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A DEMONSTRATED APPROACH FOR IMPROVING PERFORMANCE AND RELIABILITY OF BIOLOGICAL WASTEWATER TREATMENT PLANTS

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Recent documentation of biological treatment plant performance has shown that a combination of design, operation, maintenance, and administrative factor adversely affect plant performance. An approach, called a Composite Correction Program (CCP), was developed to address all factors limiting performance at individual facilities. This report documents the CCP that was implemented at the Havre, Montana Wastewater Treatment Plant and describes the resulting improvement in performance at that facility.

Francis T. Mayo, Director
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ABSTRACT

Recent documentation of the performance of publicly owned wastewater treatment facilities has indicated that a significant percentage of facilities are not meeting design and/or permit effluent quality requirements. As a result, a research activity was implemented to identify, quantify and rank the factors limiting plant performance. Comprehensive evaluations at thirty treatment plants were used to determine factors limiting performance in the areas of administration, maintenance, design and operation. In addition to the evaluation of performance limiting factors, a method (Composite Correction Programs) of improving plant effluent quality was developed during the research effort. This report describes the method which was implemented at one facility, describes the resulting improvement in performance for that facility and projects the impact on performance if similar programs were completed at all thirty facilities evaluated.

A Composite Correction Program (CCP) is designed to address all factors which limit performance at a particular facility. During this research project a CCP was implemented at the Havre, Montana Wastewater Treatment Plant. The general approach used was to improve the process control decision making capability of the plant superintendent and to eliminate administrative, minor design, maintenance and operations factors which were preventing optimum performance. Effluent quality at Havre for 6 months prior to the CCP averaged 31 mg/l for BOD_5 and 30 mg/l for TSS. Both BOD_5 and TSS concentrations averaged less than 10 mg/l for the 8-month period following initiation of the CCP and development of desired activated sludge characteristics. Between these two time periods plant BOD_5 loading increased by 27 percent, yet BOD_5 discharged to the receiving stream decreased by 68 percent.

The major conclusion documented during the Havre CCP was that this type of program must be implemented over an extended period because of the inherent long time required to effect biological process response. At Havre three months were required to achieve good activated sludge characteristics. Continued involvement for a longer time (over one year) was required to transfer to the plant superintendent the capability to maintain good process control. Continued involvement included telephone, written and person to person on-site consultation.

An analysis of the potential improvement in plant performance that could be achieved if CCP's were implemented at all thirty facilities evaluated was developed. Significantly improved performance was projected at twenty-one of the thirty facilities. If these projections were realized, the mass of BOD_5 discharged to the receiving streams would be reduced by 490 metric tons/year (540 tons/year) and the mass of TSS discharged would be reduced by 470 metric tons/year (515 tons/year). In addition, sixteen of twenty-three facilities that were found to be violating minimum secondary treatment standards could meet standards without major plant modifications that would require significant design and construction costs. Implementing CCP's is the more cost effective approach to achieving desired treatment objectives at most existing facilities, whether or not major facility design or construction changes are required.

This report was submitted in partial fulfillment of Contract No. 68-03-2224 by M & I, Inc., Consulting Engineers, Fort Collins, Colorado, under the sponsorship of the Environmental Protection Agency. Work described in this report was accomplished during the period from June, 1975 to December, 1977.

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The direction provided and assistance given by Mr. John Smith, Mr. Ben Lykins and Mr. John Sheehy, of the Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, are greatly appreciated.

SECTION I

INTRODUCTION

The "Federal Water Pollution Control Act Amendments of 1972" established goals for the quality of the nation's surface waters and programs to achieve these goals. A significant aspect of the Act was the expansion of the federal grant assistance program for the construction of new and the upgrading of existing wastewater treatment facilities. However, the U.S. Environmental Protection Agency's annual reports to Congress (1) have indicated that a significant number of facilities constructed with federal assistance were not meeting design standards and/or National Pollutant Discharge Elimination System effluent requirements. Additional reports and articles (2, 3, 4, 5) have addressed the need for improved operation and maintenance (O & M) of municipal wastewater treatment plants. These documents have pointed to the area of O & M as the leading cause of poor plant performance. However, improper or inadequate O & M has become a phrase that has been adopted to describe a broad range of performance limiting factors. Staffing requirements, operator salaries, design deficiencies, management techniques, industrial wastes, poor maintenance and inadequate budget are but a few of the items that are commonly described as O & M problems.

In an effort to define the broad area commonly described as poor O & M, a research study was funded by the EPA Office of Research and Development to identify, quantify and rank the factors causing poor wastewater treatment plant performance. Two 24-month contracts were awarded simultaneously to private engineering consultants to conduct the research effort, one in the Eastern United States and one in the Western United States. This report documents a portion of the findings of the research effort by the western contractor. A second report titled, "Evaluation of Operation and Maintenance

Factors Limiting Municipal Wastewater Treatment Plant Performance," describes the overall findings of the western contractor's research effort. (6)

During the research study a special research approach was developed to identify the causes of poor performance. This approach was used during thirty 3 to 7-day comprehensive evaluations. One of the major conclusions of the study was that a number of varied factors limited each plant's performance. Many of these factors were obvious and were being addressed by various programs implemented by the cities, state regulatory agencies and EPA. However, many of the performance limiting factors were not obvious and were not being addressed by these programs.

Analysis of the complex interrelationship of varied performance limiting factors and varied programs designed to address these factors led to the development of a Unified Concept for Achieving Optimum Plant Performance. The concept included performance limiting factors in administration, maintenance, operation and design, and described how each factor could be individually eliminated, partially eliminated or left un-addressed by existing programs associated with public wastewater treatment. The concept also related optimum performance to the many performance limiting factors associated with each plant. The elimination of only a portion of the factors limiting performance will not result in the desired improved effluent quality at a particular plant.

An approach for improving plant performance was developed in conjunction with the Unified Concept. This approach was called a Composite Correction Program (CCP). A CCP is based on optimizing the performance of an existing facility by eliminating obstructing factors in administration, design, operation and maintenance. A major difference between the CCP and many existing programs is that a CCP concentrates on eliminating all factors contributing to poor plant performance at an individual plant, whereas existing programs typically concentrate on specific areas of need representing common problems at a large number of treatment facilities.

At each of the thirty facilities which were the subject of a comprehensive evaluation in the research study, a varying degree of operational assistance was provided. The assistance was usually limited to improving process control. Assistance in other areas like administration, maintenance, design and long-term process control was usually not provided due to time and budget restrictions. However, at the Havre, Montana Wastewater Treatment Plant extensive follow-up assistance was provided throughout a full year to demonstrate the conduct of a CCP. This report describes the Havre CCP and documents the improved performance which resulted. Additionally, the potential improvement in performance was estimated for the other twenty-nine plants evaluated assuming similar CCP's were implemented at these facilities.

SECTION 2

CONCLUSIONS

1. A Composite Correction Program conducted at the Havre, Montana Wastewater Treatment Facility significantly improved plant effluent quality.

   A. Violations of permit standards were eliminated.

   B. Plant effluent BOD_5 and TSS concentrations were reduced from 31 mg/l to 10 mg/l and 30 mg/l to 9 mg/l, respectively.

2. An increase in plant personnel by one operator and an increase in plant coverage to 24-hour per day operation successfully reduced the detrimental impact of the following plant features that hindered plant operation and performance: insufficient digester volume, digester foaming problems, variable airlift return pumping rates, return plugging problems and a relatively short aeration basin detention time.

3. Detailed process evaluation during the Havre Composite Correction Program enabled a clarifier short-circuiting problem to be identified and corrected.

4. The Havre Composite Correction Program was successful because of a long time involvement with plant personnel.

   A. Twelve weeks were necessary to achieve desired changes in activated sludge characteristics.

   B. One year was required to transfer to the plant superintendent the ability to make timely and accurate process control adjustments.

5. Composite Correction Programs without major facility construction completed at the thirty evaluated facilities would improve plant effluent quality significantly.

A. Sixteen of twenty-three facilities would meet federally defined secondary treatment standards now violated. The other seven facilities would require a major facility modification to meet secondary treatment standards consistently.

B. The masses of BOD_5 and TSS discharged would be reduced by an estimated 490 metric tons per year (540 tons/year) and 470 metric tons per year (515 tons/year), respectively.

C. The masses of BOD_5 and TSS discharged would be reduced by an estimated 38 percent and 37 percent, respectively.

6. Significant differences in the performance potential for suspended growth and fixed film type facilities were noted.

A. Poor performance exhibited at fixed film facilities could not be improved significantly with a Composite Correction Program unless major facility modifications were also completed. A more conservative design is necessary for fixed film facilities.

B. Poor performance exhibited at suspended growth facilities could be improved through Composite Correction Programs without major facility modifications. Better operation is necessary for suspended growth facilities.

7. Plant underloading did not promote good plant performance. Hydraulic loading averaged only 61 percent of design, yet 23 of 30 plants did not meet secondary treatment standards.

8. Plant expansion through construction is not a satisfactory alternative to improving plant performance unless it is part of a Composite Correction Program.

SECTION 3

RECOMMENDATIONS

1. Implement Composite Correction Programs on a broad scale.

2. Modify existing operations assistance approaches to include the time associated with stabilizing a biological system.

3. Modify existing training to enable operations personnel to properly apply concepts of wastewater treatment to process control.

4. Require a more conservative design approach for fixed film wastewater treatment facilities.

SECTION 4

HAVRE COMPOSITE CORRECTION PROGRAM

The Havre, Montana Wastewater Treatment Facility, an activated sludge plant, was designed to treat an average sewage flow of 6800 cu m/day (1.8 mgd). The plant staff consisted of a superintendent, maintenance manager and two operators. The plant was operated sixteen hours per day, seven days per week. Between 1972 and 1975 the original primary treatment plant was expanded to secondary treatment. Present treatment facilities consist of grit removal, flow measurement, two aeration basins, two final clarifiers, chlorination, two aerobic digesters and a sludge lagoon. By design, the Havre facility is composed of two independent, parallel activated sludge systems. For this report one is called the "east unit" and the other the "west unit." The plant flow schematic diagram is shown in Figure 1.

The Havre CCP was completed using a four-man research team of engineers. Two senior engineers had considerable experience in plant process control, administration, maintenance and design. The initial in-plant activities for the CCP were completed in conjunction with a comprehensive research evaluation conducted by three team members from July 19, 1976 through July 26, 1976. (6) At the same time, these team members completed field work for another comprehensive evaluation at a smaller facility located in the Havre area. A follow-up half-day visit to Havre was made by two team members on August 12, 1976. Long-term telephone consultation was provided by one senior engineer, but reflected the opinions and suggestions of the entire research team.

Prior to the Havre CCP, the approach to process control had been to maintain the mixed liquor suspended solids (MLSS) concentration at about

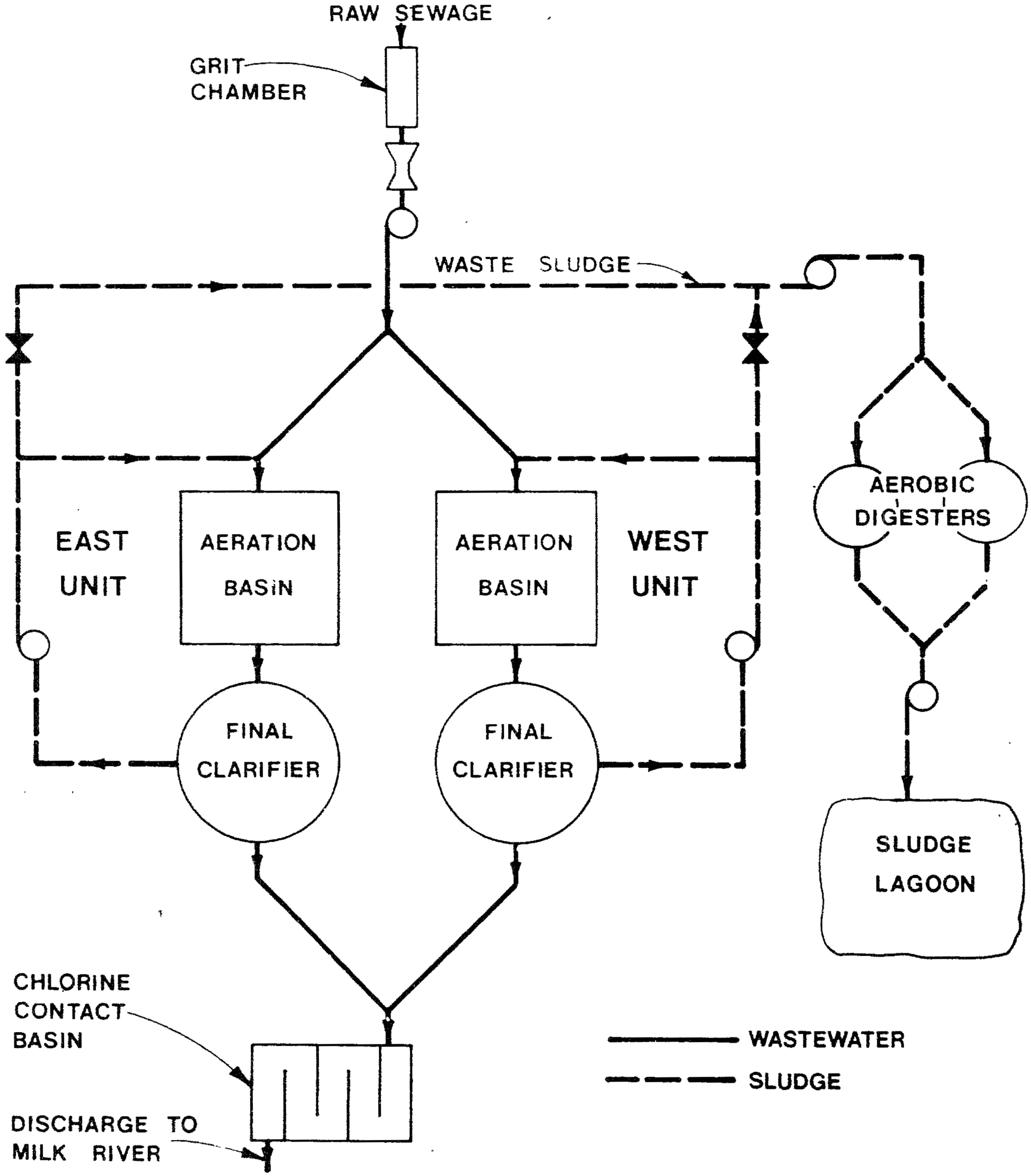

Figure 1. Plant Flow Schematic for Havre, Montana.

1,000 mg/l and to maintain the return sludge flow rate at a low, relatively constant setting (daily average sludge return rate was only 8 percent of the daily average sewage flow rate). A MLSS concentration analysis was conducted about three times per week. Based on these results, the volume of sludge wasted was adjusted.

During the initial in-plant activities, it appeared that effluent quality could be improved significantly by changing the approach used for process control. A more comprehensive testing program was initiated, including a centrifuge test on the mixed liquor, return sludge and waste sludge to determine concentrations; a settling test on the mixed liquor to determine settling characteristics; a depth of sludge blanket test to measure the level of the solids-liquid interface in the final clarifiers; and a dissolved oxygen test to determine the aeration basin dissolved oxygen concentrations (7, 8). Various daily calculations were initiated to monitor the mass of activated sludge in the system, mass wasted and mixed liquor settling characteristics. The values of selected test results were plotted so trends in system response could be observed. These trends were used to determine when to make process control adjustments.

Based on test results, dramatic process control adjustments were made in an effort to improve performance. Initially, process control decisions were made primarily by the research team. The rationale for these decisions was always discussed with the plant superintendent. As time progressed (3 to 4 months) the plant superintendent became more comfortable with test data interpretation and gradually assumed more and more of the day-to-day process control decisions. At that time the role of the research team was directed more toward providing conceptual guidance concerning the development of stable biological characteristics. Through this training approach the plant superintendent developed the capability to properly apply concepts of wastewater treatment to the operation of his facility.

PLANT PERFORMANCE

Performance of the Havre Wastewater Treatment Plant was monitored by plant personnel twice per week in accordance with the City's NPDES permit requirement. Total suspended solids (TSS) and 5-day Biochemical Oxygen Demand (BOD_5) analyses were conducted on the raw sewage influent. BOD_5, TSS and fecal coliform analyses were conducted on the chlorine contact basin effluent. All analyses were conducted on 8-hour composited samples except for fecal coliform, which was conducted on a grab sample. Monthly averages for these tests from January, 1976 through June, 1977 are shown in Table 1. The data presented is separated into three time periods. Period 1 is titled "Prior to Operations Assistance" and represents performance before the CCP was initiated. Period 2 is titled "Initial Operations Assistance" and represents performance after the CCP was initiated, but before clarifier inlet baffles were modified. Period 3 is titled "Final Operations Assistance" and represents performance after clarifier modifications were completed and better process control was achieved.

For the 6-month time frame of Period 1 the average plant effluent BOD_5 and TSS concentrations were 31 mg/l and 30 mg/l, respectively. During three of the six months, the BOD_5 and/or TSS permit standards of 30 mg/l were violated. Poor plant performance during Period 1 was attributed to an improper approach to process control and to sludge handling problems.

During Period 2 process control was being improved, but modifications to the final clarifiers were not yet made. For the 4-month time frame of Period 2, some improvement in plant effluent BOD_5 and TSS concentration was achieved. The plant effluent average BOD_5 concentration was reduced from 31 mg/l to 24 mg/l. Similarly, the plant effluent average TSS concentration was reduced from 30 mg/l to 23 mg/l.

During the 8-month time frame of Period 3, a significant improvement in plant effluent quality occurred even though the plant influent wastewater strength increased. Better plant effluent quality was primarily attributed to modifications to the final clarifiers and better process control. From

TABLE 1. SUMMARY OF PERFORMANCE DATA FOR THE HAVRE, MONTANA WASTEWATER TREATMENT PLANT.

		BOD$_5$			TSS			Fecal Coliform
	Flow (MGD)*	Plant Influent (mg/1)	Plant Effluent (mg/1)	% Removal (%)	Plant Influent (mg/1)	Plant Effluent (mg/1)	% Removal (%)	Geometric Mean (#/100 ml)
PERIOD 1 - PRIOR TO OPERATIONS ASSISTANCE								
Jan 76	1.30	332	17	94.9	199	27	86.4	630
Feb	1.26	250	41	83.6	236	36	84.7	475
Mar	1.29	251	29	88.4	204	25	87.7	32
Apr	1.34	259	37	85.7	281	42	85.1	112
May	1.29	283	34	88.0	251	29	88.4	73
Jun	1.37	278	26	90.6	266	22	91.7	54
Average	1.31	276	31	88.5	240	30	87.5	127
PERIOD 2 - INITIAL OPERATIONS ASSISTANCE								
Jul 76	1.16	251	19	92.4	261	19	92.7	87
Aug	1.14	212	21	90.1	220	18	91.8	1109
Sep	1.11	292	28	90.4	212	33	84.4	450
Oct	1.22	234	27	88.5	198	22	88.9	120
Average	1.16	247	24	90.4	223	23	89.4	269
PERIOD 3 - FINAL OPERATIONS ASSISTANCE								
Nov 76	1.33	225	11	95.7	213	14	93.4	29
Dec	1.33	239	7.9	96.7	230	9.6	95.8	35
Jan 77	1.37	328	12	96.3	215	8.6	96.0	23
Feb	1.48	357	11	96.9	258	10	96.1	35
Mar	1.34	423	6.8	98.4	302	8.1	97.3	12
Apr	1.39	438	8.0	98.2	307	9.4	96.9	61
May	1.34	387	12	96.9	261	7.3	97.2	53
Jun	1.27	379	8.9	97.7	322	5.4	98.3	50
Average	1.36	351	9.7	97.1	264	9.1	96.4	31

* MGD x 3785 = cu m/day

Period 1 to Period 3 the raw sewage BOD_5 concentration increased 27 percent (i.e., 276 mg/l to 351 mg/l), yet plant effluent BOD_5 concentration decreased 69 percent (i.e., 31 mg/l to 9.7 mg/l). The improvement in plant effluent quality represents a reduction in mass of BOD_5 discharged to the stream of 104 kg/day (229 lb/day). Similarly, the mass of TSS discharged was reduced by 102 kg/day (225 lb/day).

As a result of the CCP, an improvement in disinfection performance also occurred. The geometric mean fecal coliform count decreased from 127 per 100 ml during Period 1 to 31 per 100 ml during Period 3. Other benefits were lower chlorine dosage requirements and less chlorine contact basin maintenance. The chlorine dosage was reduced to maintain a chlorine residual less than the maximum allowable concentration of 0.5 mg/l. In fact, a smaller rotometer had to be installed on the chlorinator to obtain the required lower dosages. The chlorine cost saving was an estimated 40 percent, or $700 per year. Less chlorine basin maintenance was required because less basin cleaning was necessary. Prior to Period 3 the effluent TSS concentration was decreased by 30 percent through settling within the chlorine contact basin. Solids removal in the contact basin allowed permit violations to be less flagrant, but required repeated basin cleaning. During Period 3 these solids were captured in the final clarifiers, and the time previously spent cleaning the chlorine contact basin was used for additional process testing, preventive maintenance and general housekeeping activities.

The improvement in plant performance at Havre is illustrated in Figure 2, where 7-point moving averages of chlorine contact basin effluent BOD_5 and TSS concentrations are shown. The 7-point moving averages were used to smooth the variability in individual data points so trends in performance could be readily observed. As shown in Figure 2, plant effluent BOD_5 and TSS concentrations decreased over the 18-month period from January, 1976 to June, 1977, and were at or near 10 mg/l during the last 7 months. It should be noted that the graph in Figure 2 is separated into operational phases rather than the performance periods described earlier. Each of the four phases shown represents a different operational objective that was established during the CCP. Each phase is discussed later in this report.

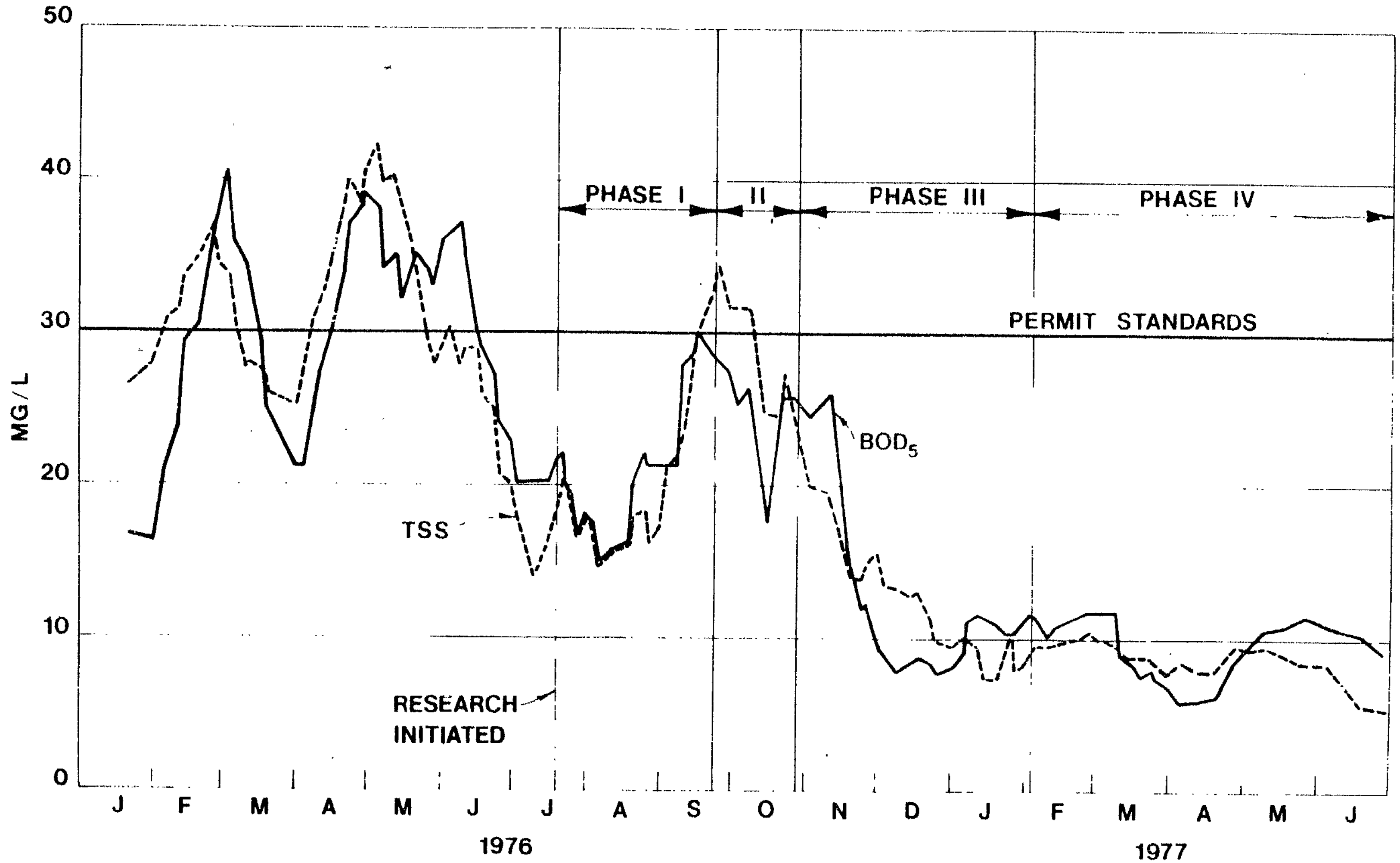

Figure 2. Chlorinated effluent BOD_5 and TSS concentrations at Havre, Montana.

Other benefits of improved effluent quality were operator pride in good performance and city pride in a good operating facility. These benefits could not be tangibly measured, but nevertheless existed. In addition, the plant was a training facility for local college students studying Water and Wastewater Treatment Technology. Students frequently visited the plant for on-the-job instruction. Observing a well performing, full-scale plant accentuated their on-site training.

PROGRAM DESCRIPTION

The first step in implementing the CCP at Havre was to establish a sampling and testing program to monitor process control parameters. Based on these results, control adjustments were made. Many factors contributed to the specific operations decisions made. Most important among these were aeration basin size, clarifier size, wastewater strength, sludge wasting capability and return sludge flow controllability. The aeration basin sewage detention time averaged 6.7 hours. The clarifier surface settling rate averaged 13.6 cu m/day/m^2 (330 gal/day/ft^2). The Havre clarifiers had a surface area which was well developed with overflow weirs and effluent launders. Return activated sludge was withdrawn from each of the clarifiers through a center hopper. The return sludge flow rate was adjusted and was measured, but varied with changes in return sludge density. The wastewater strength, as measured by TSS and BOD_5, was relatively high. Controlled, incremental wasting was completed every hour of the day by adjusting time clock settings. Waste activated sludge was directed to two aerobic digesters (total capacity 1000 cu m (270,000 gallons)) then to a digested sludge holding lagoon with an approximate volume of 30,000 cu m (7.9 million gallons). This combination of sludge handling facilities was sufficient so that plant operation was not limited by inadequate sludge wasting capacity during the CCP. However, it should be noted that at the required wasting rate the sludge lagoons were projected to be filled about twice as fast as was projected in the plant design.

Settled activated sludge in the clarifiers was returned to the aeration basins with air-lift pumps. A problem existed with return sludge flow control in that once set, the flow rate did not stay constant. Moderate changes in the return sludge density caused significant changes in the return sludge flow rate. A change in density occurred when the clarifier scraper blade pushed sludge into the center hopper. A variable return sludge flow rate occurred frequently during those portions of the project when rapid sludge settling conditions existed. A slower, yet adequately settling sludge helped alleviate this problem to a degree.

Separate waste activated sludge pumps for each activated sludge unit pumped waste sludge from the return activated sludge line to the aerobic digesters. Each waste sludge pump was operated through a separate time clock. Activated sludge wasting was automatically completed every hour. The amount wasted was adjusted by changing the time clock settings. The operators measured the waste sludge concentration every 4 hours which, combined with the waste sludge volume information, resulted in good documentation and control over the mass of sludge wasted.

Sludge was wasted to one of two aerobic digesters. Aerobic digester volume was not sufficient for complete digestion (hydraulic detention time of 8 days), but during the survey nearly unlimited ultimate sludge disposal capability allowed the desired quantities of sludge to be wasted from the activated sludge process. Partially digested sludge (specific oxygen uptake rate of 6 mg O_2/gm VSS/hr where 1 mg O_2/gm VSS/hr is considered digested) (9) was pumped to a sludge holding lagoon away from the city. The lagoon had storage capacity for several years' sludge accummulation. The lagoon location in relation to prevailing winds was favorable and no odor complaints were received concerning the lagoon.

At Havre, the key to good performance was maintaining activated sludge settling characteristics which were most desirable for the plant design and loading conditions. It was important to conduct settling tests that appropriately depicted the sludge settling characteristics. A one-hour settling test using a Mallory settleometer was initiated to fulfill this need (7, 8). The results of this settling test are graphically illustrated in Figures 3 and 4 for the east and west activated sludge units, respectively. These graphs

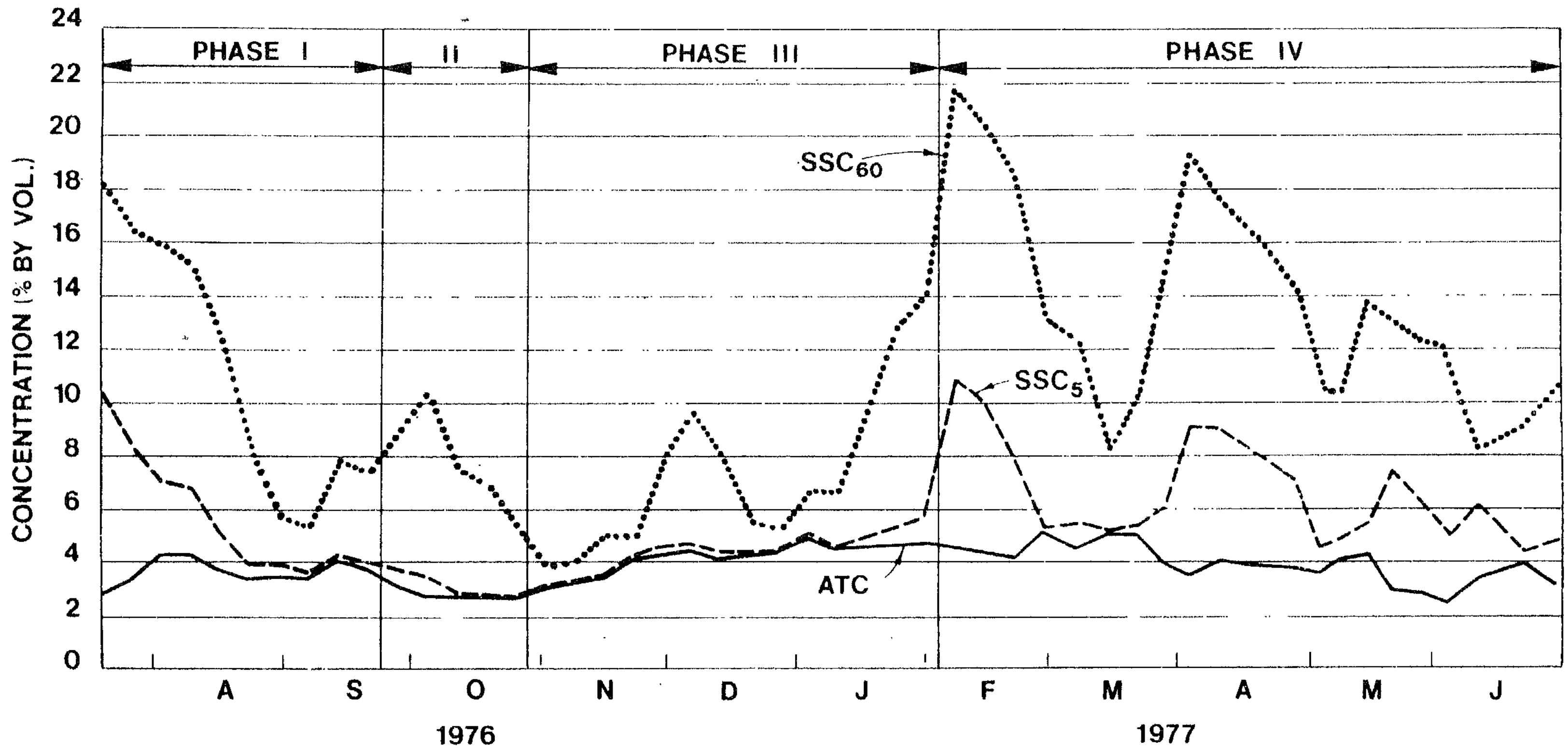

Figure 3. East unit settled sludge concentrations (SSC) at Havre, Montana.

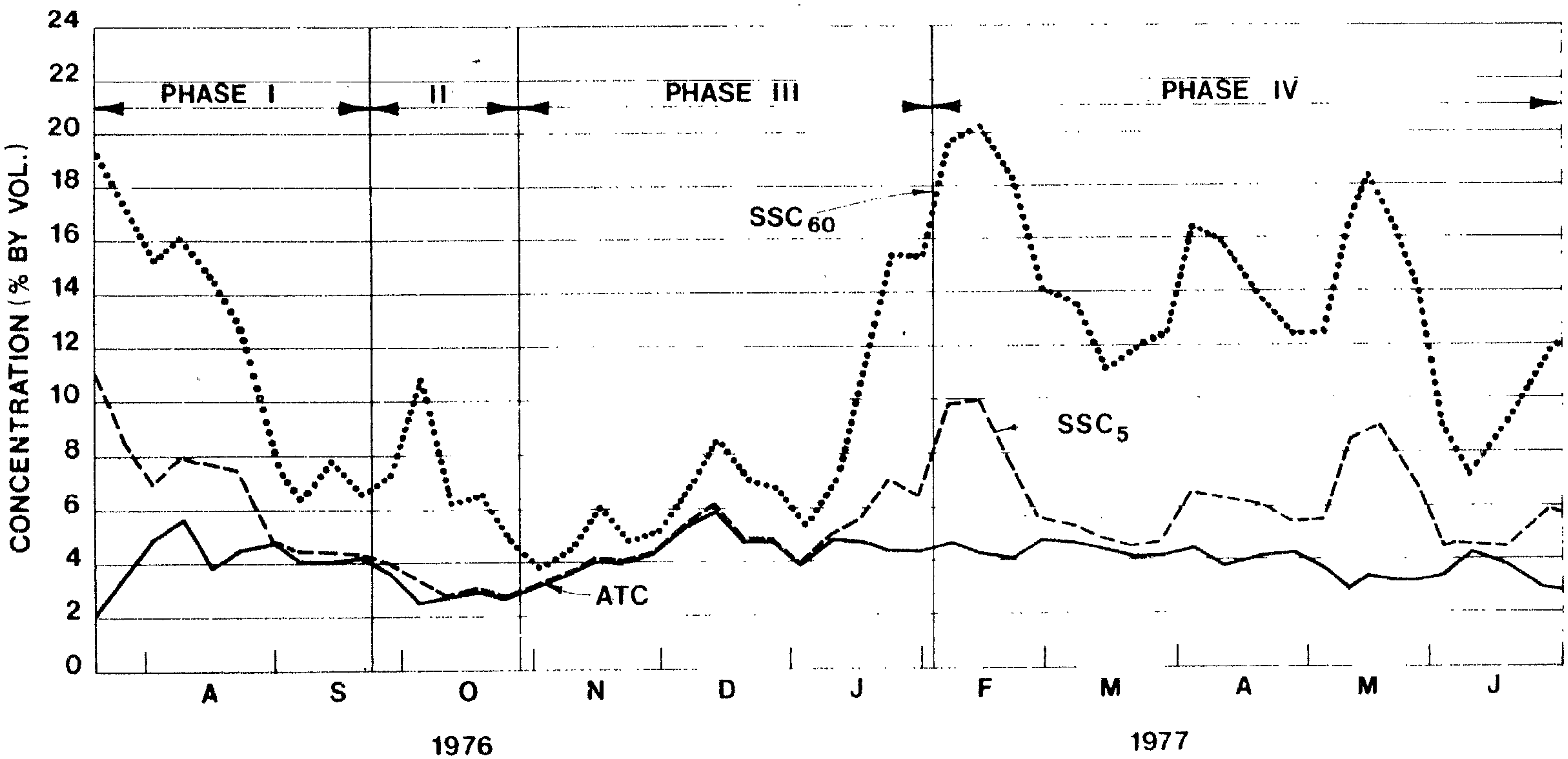

Figure 4. West unit settled sludge concentrations (SSC) at Havre, Montana.

show trends in settling characteristics in terms of ATC, SSC_5 and SSC_{60} where:

ATC = Aeration Tank Concentration in percent by volume using a centrifuge. SSC_5 and SSC_{60} are the Settled Sludge Concentrations calculated using the initial measured concentration (ATC) and the volume of sludge in the settleometer after the indicated time (t) of settling (SSV_t). The equation for this calculation is:

$$SSC_t = \frac{ATC\ (1000)}{SSV_t}$$

In Figures 3 and 4, poor activated sludge characteristics of slow settling are indicated by a low value for both SSC_5 and SSC_{60}. Poor characteristics of too rapid settling are indicated by high SSC_5 and SSC_{60} values. Desired characteristics of uniform settling are indicated by a low value for SSC_5 and a high value for SSC_{60}.

The SSC concentrations were used in lieu of the more conventional sludge volume index (SVI) because SSC values more completely described the sludge settling characteristics. The two SSC values depicted the settling pattern throughout a one-hour time period, rather than at the single 30-minute time period as with the SVI test. For example, high SSC_{60} values indicated that the sludge had the ability to settle and concentrate. The added SSC_5 value indicated rapid or slow initial settling. Rapid initial settling was typically accompanied by a cloudy effluent that had a relatively high BOD_5 concentration. A low value of SSC_5 in association with a higher SSC_{60} value was accompanied by a clear effluent as well as with a concentrated settled sludge.

The settling graphs in Figures 3 and 4 are separated into the four operational phases also shown in Figure 2, which was discussed earlier. Each of the four phases represents a different operational objective or event.

Phase I

Phase I occurred for nine weeks beginning with the start of the CCP. Initially, the activated sludge in both the east and west units settled very fast (high SSC_5 and SSC_{60} values) and left a cloudy supernatant. A relatively cloudy final clarifier effluent existed, and the plant effluent BOD_5 concentration was higher than the associated TSS concentration, as shown in Figure 2. The ATC values were relatively low at about 2.5 percent by volume, and a large portion of the total system activated sludge mass was retained in the clarifiers because of an extremely low return versus wastewater flow percentage (8 percent). During Phase I significant changes in plant operation were made. The first operational objective was to improve the BOD_5 and TSS removal capability of the activated sludge.

After the initial process control test results were obtained, the return versus wastewater flow percentage was increased from 8 percent to between 40 and 50 percent. However, very poor control over the return sludge flow rate existed. The return sludge flow rate that was set varied considerably due to plugging problems, and sometimes the return sludge flow stopped altogether when left unattended. The need for better return sludge flow control was a routine topic of discussion between the plant superintendent and the research team. It appeared that a design modification was required to eliminate the return sludge plugging problem. However, it was also determined that expanded operator attention could replace the need for an immediate design modification to the return sludge facilities. In addition, aerobic digester foaming problems also required expanded operator attention. Based on these needs, the superintendent successfully presented a request to the city council for approval to hire one additional operator and to expand from 16 hour, seven day-per-week operation to 24 hour-per-day operation for five days and 16 hour-per-day operation for two days of the week. This administrative decision eliminated the immediate need for the return sludge design modification and substantially aided in overall plant operation.

Other process control changes were made at the same time the return versus wastewater flow percentage was increased. The mass of activated sludge in both the east and west units was increased to improve its BOD_5 and TSS removal capability. An indication of the relative increase in activated sludge mass is shown in Figures 3 and 4 in terms of the ATC values. The ATC's were increased and maintained, through wasting, at an initially selected level of 3.7 percent by volume for the east unit and 4.2 percent by volume for the west unit. In both units the activated sludge character began to change. Both the SSC_5 and SSC_{60} values began to decrease, indicating slower overall settling, and the supernatant in the settleometer began to become less turbid. The final clarifier effluent clarity improved and the plant effluent BOD_5 concentration began to decrease (See Figure 2 at the start of Phase I). However, the activated sludge began to rise in the settleometer prior to the conclusion of the 60-minute settling tests. At the same time, a heavy scum layer developed on the surface of both final clarifiers and an increase occurred in the amount of activated sludge solids lost in the clarifiers' effluent. Figure 2 shows increased TSS and BOD_5 concentrations in the plant effluent toward the end of Phase I. It is important to note that nine weeks had elapsed since the CCP had been initiated and plant effluent quality had not yet stabilized at an improved level. In fact, plant effluent quality was deteriorating. The plant operators were discouraged, but continued to stay with the project because, according to the plant superintendent, "We believed in the basic concepts and felt that, logically, it should work."

Process response at the conclusion of Phase I was confusing in that, based on the control test data, rising sludge should not have occurred and excessive solids should not have been lost over the clarifier weirs. The SSC_{60} value was only about 7 percent, and based on experience much higher SSC_{60} values had been associated with rising sludge conditions. Also, the total mass of sludge in each activated sludge unit was too low to expect rising sludge characteristics. Typically, rising sludge characteristics had been observed at other facilities when a relatively high and "older" mass of sludge existed. During a typical CCP a plant visit would have been conducted to "tie-in" control test data with on-site observations. Budget constraints prohibited this option.

Phase II

Phase II occurred for five weeks and incorporated a short-range operation's objective to eliminate the rising sludge condition and associated scum problems. A decision was made to decrease the mass of activated sludge in both systems through increased wasting, and thereby lower the "age" of the sludge. This decision was made even though it was known that the existing, relatively low quantity of activated sludge in the system and slower sludge settling characteristics did not indicate an "old" sludge condition could be causing the problems. Subsequently, two events occurred with respect to the activated sludge character. The sludge settling rate was further decreased and the sludge rising condition was eliminated. Slower overall settling was documented through the SSC_{60} values, which decreased from about 7 percent to about 5 percent in both the east and west units.

It was anticipated that a reduced system activated sludge inventory would decrease the SSC_{60} value and would yield a very clear supernatant in the settleometer (i.e., produce a bulky sludge). It was also felt that a good quality effluent could be achieved if the sludge blanket could be contained in the final clarifiers. It was realistically anticipated that a fairly bulky sludge could be contained in the final clarifiers because of their relatively low overflow rates at about 13.6 cu m/day/sq m (330 gal/day/ft^2).

When wasting was increased and total system activated sludge mass was decreased, the SSC_{60} values decreased and the supernatant clarity in the settling test jar improved - both as predicted. Activated sludge was contained in the final clarifiers and their effluent was relatively clear, but for an unknown reason the clarifiers' effluent contained excessive discreet floc particles. This situation should not have occurred when the clarifier sludge blanket was being contained. It was felt that additional influences were possibly interfering with biological system response. A plant visit would have been desirable but was not feasible due to budget constraints. The possibility of some outside influence was discussed with the plant superintendent. The superintendent reported that since the rising sludge condition had stopped and the scum problem had dissipated, he was able to observe what appeared to be short-circuiting in the final clarifiers.

During the initial on-site efforts of the Havre CCP, it was observed that the operators had modified the clarifier inlet baffles. The baffles had been cut-off about 15 cm (6 in) below the clarifier water surfaces in order to decrease the build-up of trapped scum and to eliminate freezing problems that had occurred during the previous winter. This modification is illustrated in Figure 5, and proved to be the source of much of the confusion in process response that was described earlier. When the inlet baffles were modified some of the mixed liquor that entered the clarifier overflowed the inlet baffle. This condition did not represent a problem when the activated sludge settling rate was fast, as existed during the initial on-site efforts. However, when the activated sludge settling rate decreased, solids traveled across the clarifier surface toward and over the effluent weirs before they settled out. This short-circuiting situation became pronounced toward the end of Phase I and during Phase II when the activated sludge settling rate was much slower. The short-circuiting problem became more visually apparent at the end of Phase II when the scum on the clarifier surface had dissipated.

After discussing the effects of the inlet modification with the plant superintendent, a decision was made to drain down the clarifiers and weld back on the portions of the inlet baffles that had been removed. This task was accomplished, and an immediate significant improvement in plant effluent quality occurred even though the activated sludge settling rate was still very slow.

Phase III

The elimination of clarifier scum and short-circuiting marked the beginning of another operations objective and the start of Phase III. Effluent quality had improved significantly, but activated sludge settling characteristics had not yet improved. A decision was made to increase system activated sludge mass and to again work toward improving the settling rate. The activated sludge wasting rate was reduced and sludge mass was increased to a pre-

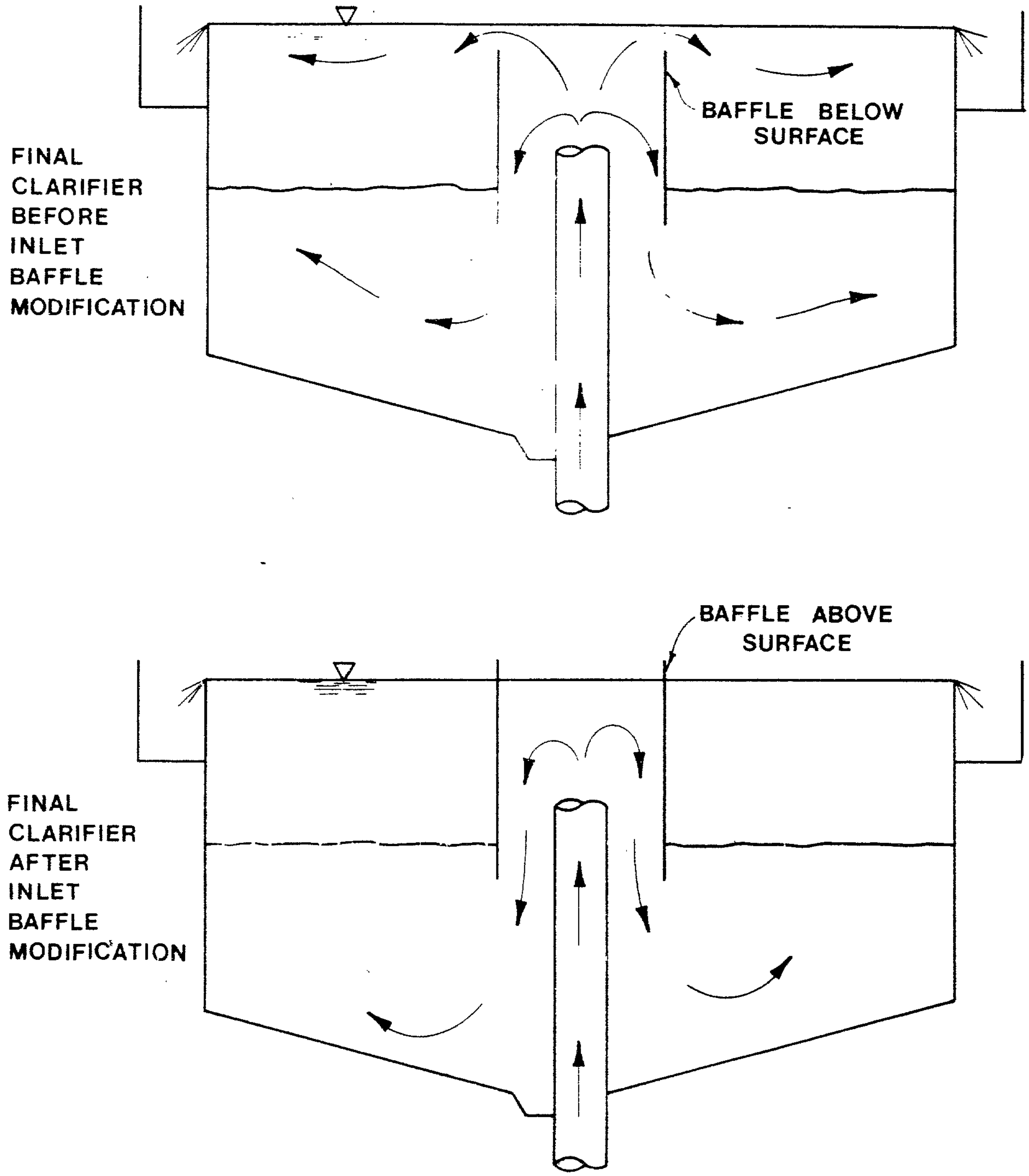

Figure 5. Final clarifier modification at Havre, Montana to stop short-circuiting.

selected higher value. The increase in quantity of activated sludge in the system occurred in both the aeration basins and clarifiers. The quantity increased in the aeration basin is shown in Figures 3 and 4 in terms of the ATC value. After holding the ATC at a higher value for about six weeks, the activated sludge settling rate began to improve. The SSC_{60} increased from about 4 percent to about 9 percent in both the east and west activated sludge units. At that time, problems were encountered with the ultimate sludge disposal pump. Sludge in the aerobic digesters could not be pumped to the sludge lagoon, thus activated sludge could not be properly wasted to the digesters from the activated sludge systems. Due to the relatively long time that was necessary to improve the activated sludge characteristics to the point which had been achieved, it was decided to protect the east unit sludge characteristics by continuing to waste from the east unit to the west unit. However, the method of wasting from the east unit to the west unit was very difficult to control, and a wide fluctuation occurred in both the east and west unit activated sludge masses. A stable plant operation did not exist, and the net effect was a decrease in the activated sludge settling rate for both units during the one and one-half week period for which the pump was out of service. These results dramatically pointed out to plant personnel the need for additional spare parts and better emergency maintenance procedures.

The activated sludge settling rate continued to be relatively slow even after the pump was repaired and placed into service. The SSC_{60} decreased from about 9 percent before the pump failure to about 5 percent. It should be noted that during the Phase III bulky sludge conditions, as shown in Figures 3 and 4, the TSS concentration of the final effluent was greater than the BOD_5 concentration, as shown in Figure 2. The BOD_5 and TSS concentrations were relatively low, but not as low as could be achieved. After the ultimate sludge disposal pump was repaired, the activated sludge system masses in both units were again held at a controlled, higher level to encourage improved activated sludge settling characteristics. After four weeks the activated sludge settling rate began to improve, but continued to increase beyond the point desired. A drastic increase in the activated sludge settling rate during Phase III is shown in the settling data in Figures 3 and 4. During this very rapid settling condition, the operators reported a more cloudy appearance of the supernatant in the settleometer and in the clarifier effluent. Also, the BOD_5 concentration of the final effluent increased and the TSS concentration decreased. The desired situation of both decreased BOD_5 and TSS and a stable plant operation did not yet exist.

It is noted that the Havre final effluent quality was always quite good after the clarifier short-circuiting problem was eliminated. Even during periods of slow activated sludge settling rates, poor effluent quality was not experienced. The primary reasons for a relatively good quality effluent during slow activated sludge settling conditions was the combined benefits of a wastewater flow rate less than design and a relatively conservative clarifier design size. This reserve capacity is typically not available at most wastewater treatment plants, yet other installations require the same general approach in order for an improvement in performance to occur. Correct operational decisions must be made and adequate time must be allowed to achieve system response. At Havre, approximately 12 weeks elapsed from the time a decision was made to increase the ATC's to the time an improvement occurred in the activated sludge settling rate. A disruption was encountered due to problems with the ultimate disposal sludge pump, but some type of disruption was not totally unexpected. During the 12-week time frame no significant changes in the aeration basin dissolved oxygen (D.O.) concentration or return sludge flow percentage were made. The aeration basin D.O. concentration varied from about 4 mg/l to 7 mg/l. The return sludge flow percentage was about 40 percent. Also, no chemicals were added to the system to change sludge character. The most important observation was that three months elapsed before the activated sludge developed more desirable settling characteristics.

Phase IV

The development of a rapid activated sludge settling rate marked the beginning of another operations objective and the start of Phase IV. The active sludge mass in the system was slightly decreased in an effort to slow down the activated sludge settling rate and improve its BOD_5 removal capability. Also, "fine tuning" of the activated sludge process was initiated to provide the plant operators better control over the activated sludge settling characteristics. The mass of sludge wasted, return sludge flow rates and dissolved oxygen concentrations were all more carefully controlled. The biological system was maintained at a point of relative stability through continual operations adjustments. The superintendent slightly reduced the ATC to slow down the settling rate and improve its BOD_5 removal capability and slightly increased the ATC to speed up its settling rate and improve its manageability through better containment within the final clarifiers. Small variations in activated sludge characteristics and plant effluent quality occurred, but timely operations adjustments prevented large fluctuations and eliminated extended periods of poor performance. For an 8-month period the plant effluent BOD_5 and TSS concentrations averaged 10 mg/l and 9 mg/l, respectively. The plant superintendent justifiably believes that this high degree of treatment can be achieved consistently.

DISCUSSION

The Havre CCP demonstrated that significantly improved performance could be achieved using existing wastewater treatment facilities. Improved performance occurred after several modifications were made to plant operation, design, administration and maintenance. The plant operator's ability to apply concepts of process control at his facility was improved. A minor modification to the clarifiers was made. An administrative change regarding plant staffing was implemented. The necessity of a good preventive maintenance program was reinforced. The CCP also identified the process control parameters that were most critical at the Havre plant with its particular physical facilities.

The most critical process control parameter at Havre was the sludge settling rate as controlled by the ATC. It was determined that the Havre activated sludge system performed best when the sludge settling rate was relatively slow (i.e., demonstrated bulky sludge conditions). The reasons for this were associated with the relatively short aeration time and associated high BOD_5 loading rate, and the relatively large clarifier size which enabled the slower settling sludge to be contained in the systems. The Havre plant operated well under these conditions, but very close operator attention was required to maintain the desired sludge characteristics. For example, wasting was often drastically adjusted each day in order to maintain the desired ATC. The existing Havre facility will always require strict operations control to achieve a stable operating condition, which will become even more pronounced when the wastewater flow rate to the facility increases. The present good effluent quality associated with relatively slow activated sludge settling rates may not occur as the wastewater flow rate increases. However, through continued timely adjustments of the critical process control parameters, the plant effluent quality should meet the existing NPDES Permit standards at least until the plant design flow rate is reached.

It is expected that other wastewater treatment facilities will have different critical process control parameters, depending on their specific design arrangement, wastewater strength and other unique features. For example, in plants that have a longer aeration basin wastewater detention time, somewhat less exact control would be expected to maintain a stable operating condition. In plants that have a proportionately smaller clarifier and a higher clarifier surface overflow rate, more difficulty would be encountered to operate through bulky sludge characteristics. It is not expected that all facilities could get into or out of a bulky sludge condition by following the specific values for ATC, return rate, D.O. concentration and other control variables which were discussed in this report.

A major reason for the success of the Havre CCP was the extended length of time over which the program was conducted. It was noted earlier that twelve weeks were required to develop a desired activated sludge settling rate. Additional time was required to transfer the process control decision making capability to the plant superintendent. The time required to develop desired activated sludge settling characteristics at other facilities could easily be equal to or greater than the time required at Havre. This time requirement in itself supports the conclusion that CCP's must be implemented over a long time period (i.e., three to six months). However, additional time (i.e., one to two years) is necessary to adequately transfer to plant personnel the ability to make timely and accurate in-plant control adjustments.

After a 4-month period, the Havre superintendent satisfactorily made all short-range control decisions, such as determining wasting requirements to maintain a desired ATC. After nearly a year the superintendent was also making long-range decisions, such as selecting the desired ATC value. A 1-year time period was necessary even though the superintendent had two years of general administration college training, had received formal training for two years at a water and wastewater technology school and had an excellent aptitude and personality. It should also be noted that the superintendent continues to discuss plant operation and performance with the research team on a periodic basis in order to obtain a second opinion on major control decisions. His not relying on, but using available help to the advantage of his operation, illustrates the security which he has developed that accompanies the competency which he has achieved. The success of CCP's is equally dependent upon developing optimum biological conditions and developing operator competency. Both are time consuming functions.

A major conclusion of the overall research study, for which the Havre CCP was one segment, was that presently there are not a sufficient number of persons with adequate background and training to successfully conduct CCP's on a broad scale. (6) One reason for this occurrence is that a need for these services has not been developed due to inadequate enforcement and a general "construction" approach to achieving better plant effluent quality. Another reason is that process control "authoritative sources," such as consulting engineers, regulatory personnel, equipment suppliers and others have not correctly approached operations assistance. Generally, persons who give technical guidance at biological wastewater treatment plants do not observe system response for a long period of time. As a result, most do not understand the consequences of their suggestions and seemingly good suggestions may be incorrect, or correct for the present situation but incorrect at a later date. Process control suggestions made under these circumstances lead to improper technical guidance. Furthermore, failure to observe system response over the time frame required to see the full impact of recommendations made does not promote the improvement of technical assistance capability. Conversely, the approach taken at Havre allowed both plant personnel and research team members to use the project as a learning experience. In so doing, research team members have expanded their assistance capabilities.

Because of the success with the Havre CCP and the obvious need for improved performance at a large number of the facilities studied under the research contract, an analysis of conducting similar CCP's at other facilities was completed. This analysis and the projected benefits are presented in the next section of this report.

SECTION 5

PROJECTED IMPROVEMENT THROUGH COMPOSITE CORRECTION PROGRAMS

This section of the report describes the potential improvement in plant effluent quality which could be achieved if CCP's without major facility upgrades were conducted at all thirty facilties for which an evaluation was made during the overall research effort. (6) Also described is the actual improvement in performance which occurred at some facilities as a result of the research evaluations. Some operations assistance was provided to aid in the collection of research data. The success of this assistance in improving performance was dependent upon the number and type of performance limiting factors encountered. Telephone communication similar to that used during the Havre CCP was maintained with some facilities. Generally, technical assistance provided during the research evaluations included only operations factors limiting performance, and was specifically limited to improving the operations capabilities of the process control decision maker. In a few cases, minor plant modifications were made. The scope of these assistance efforts was considerably less than the effort expended during the Havre CCP. Improvement typically was not documented to the same extent. In addition, it could not be predicted that these plants would continue to perform at the improved level.

Improved performance occurred at seven facilities, including Havre. During the Havre CCP, activated sludge characteristics went through several different and typical changes: bulky, scum-producing, rapid settling and optimum. When combined with extensive operations help, this guided observance and control of different activated sludge characteristics allowed for the transfer of process control capability and process understanding to the Havre superintendent. This time-related training was not completed at the other six facilities where improved performance occurred.

The research evaluations of various treatment plants were limited to facilities whose wastewater flow rate was less than 37,850 cu m/day (10 mgd). Facilities were evaluated with flows ranging from 26 cu m/day (0.007 mgd) to 30,660 cu m/day (8.1 mgd). The average wastewater flow rate for the thirty facilities evaluated was 5070 cu m/day (1.34 mgd). Statistically, the size range of the facilities studied represents the largest number of wastewater treatment plants in the United States.

Each of the facilities studied must discharge an effluent that does not violate the federally defined minimum secondary treatment standards. Some were required to meet more stringent effluent requirements. Twenty-three of the thirty facilities studied were not achieving desired effluent quality at the start of the research evaluations. The improvement in performance which occurred as a result of the research evaluation and the additional improvement which could occur if CCP's were implemented at all facilities are discussed. Improvement in effluent quality is described in terms of reduction of total mass of pollutants discharged. The reduction of mass of pollutants discharged is significant relative to the size range of plants evaluated. It is also significant when described in terms of a percentage improvement from the former status.

REDUCED POLLUTANTS IN THE PLANT EFFLUENT

For discussion purposes, the thirty facilities evaluated were grouped into three categories: 1) Plants for which an improvement in performance did occur, 2) Plants for which an improvement in performance could occur by implementing a CCP and 3) Plants for which a significant improvement in performance is doubtful without major expansion or modification of the existing treatment facilities. The associated improvement for each of the thirty facilities is presented in Tables 2, 3 and 4, which correspond to the above categories. In the tables, each facility is discussed separately.

Although it cannot be predicted that the plants in Table 2 will maintain the improved performance achieved as a result of the research evaluation, the improvement that occurred and the level of treatment indicated could be

TABLE 2. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE DID OCCUR

Plant No.	Flow		Before		After		Reduction				Plant Type - Comments
	Actual mgd*	Design mgd	BOD mg/l	TSS mg/l	BOD mg/l	TSS mg/l	BOD		TSS		
							lb/day**	ton/yr***	lb/day	ton/yr	
022	0.012	0.015	35	60	10	10	2.5	0.5	5.0	0.9	Activated sludge, extended aeration, with polishing pond. The return sludge flow rate was excessively high, causing solids loss over the clarifier weir. The R/Q ratio was reduced from about 1000% to about 100%, and excessive solids loss was eliminated. Presently, all treated sewage flows through a polishing pond. A pond bypass should be installed to discharge good final clarifier effluent to the receiving stream.
029	1.36	1.8	31	30	9.7	9.1	242	44	237	43	Activated sludge, conventional, without primary clarifier. Changes in return and waste sludge control procedure were implemented and a plant deficiency was corrected. The values shown represent a six-month average for "Before" data and an eight-month average for "After" data.
048	0.34	0.38	68	116	10	10	164	30	300	55	Activated sludge, conventional, without primary clarifier. Insufficient wasting was completed. Only about half of the sludge grown each day was wasted. The remainder bulked over the clarifier weir. The NPDES standards were violated but not reported as such. Increased wasting controlled sludge bulking. The plant has an I/I problem. If the I/I problem was corrected, the facility should continue to perform well.
050	0.17	0.18	45	80	10	10	50	9.1	100	18	Activated sludge, extended aeration, without primary clarifiers. Insufficient sludge wasting was completed. The approach was to "build solids". The NPDES permit standards were violated but were not reported as such. Increased wasting controlled sludge bulking. Operations testing and process controls were implemented and good effluent quality maintained.

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)

TABLE 2. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE DID OCCUR (Continued)

Plant No.	Flow		Before		After		Reduction				Plant Type - Comments
	Actual mgd*	Design mgd	BOD mg/l	TSS mg/l	BOD mg/l	TSS mg/l	BOD lb/day**	BOD ton/yr***	TSS lb/day	TSS ton/yr	
053	0.11	0.16	32	50	10	10	20	3.7	37	6.7	Activated sludge, extended aeration, without primary clarifiers. Insufficient sludge wasting. The approach was to build solids to a specified level (3000 mg/l). The return rate was too high and too much "scum" recycle was directed back to the aeration basin to reach a MLSS of 3000 mg/l before solids bulking occurred. Decreased return, controlled scum withdrawal, and increased wasting, as well as implementation of operations testing and process controls were completed, and good effluent quality was maintained.
060	0.49	1.05	45	37	35	27	41	7.5	41		[illegible] primary clarifier [illegible] bio-filter system). A [illegible] liquor to the chlorine contact basin influent was found. Plant effluent still does not meet NPDES standards because of design limitations in aeration capacity.
061	0.17	0.50	37	42	10	10	38	7.0	45	8.3	Activated sludge, contact-stabilization, without primary clarifier. Inadequate wasting and return control provided. Sludge wasted to an aerobic digester and recycled back into activated sludge system. Return flow rate not controlled. Operations testing and process control were implemented and good effluent quality maintained. A plant piping modification should be completed to operate conventionally rather than with the contact-stabilization mode to facilitate operation. In addition, nearly half the operations cost could be saved by operating only one of the two plants presently on line (one was recently completed).
TOTAL	2.652	4.085	N/A	N/A	N/A	N/A	557.5	101.8	765	139.4	

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)

TABLE 3. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE COULD OCCUR

Plant No.	Flow Actual mgd*	Flow Design mgd	Present BOD mg/l	Present TSS mg/l	Potential BOD mg/l	Potential TSS mg/l	Reduction BOD lb/day**	Reduction BOD ton/yr***	Reduction TSS lb/day	Reduction TSS ton/yr	Plant Type - Comments
002	0.43	0.8	65	117	10	10	197	36	384	70	Activated sludge, extended aeration, without primary clarifiers. Inadequate process understanding and control, and inadequate clarifier surface development causes uncontrollable excessive solids loss.
007	0.041	0.07	54	130	10	10	15	2.8	41	7.5	Activated sludge, oxidation ditch, without primary clarifier. Inadequate sludge wasting capability at the plant, as well as inadequate process understanding, testing, and control causes excessive solids loss.
012	8.1	12.0	40	35	30	30	676	123	338	62	One-half trickling filter and one-half trickling filter followed by contact-stabilization with anaerobic digestion. Inadequate flexibility in digester operation, which could be provided with a relatively small piping change, causes excessive TSS in digester supernatant recycle and degraded plant performance. Improved performance would probably not meet standards consistently.
013	0.5****	0.8	22	32	10	10	50	9.1	92	17	Activated sludge, conventional, without primary clarifiers and with polishing pond. Insufficient wasting, inadequate process understanding, testing and control, and inadequate clarifier surface development causes excessive solids loss. In addition, there was not a pond bypass to discharge good clarifier effluent when the pond effluent was poor.

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)
**** Flow during survey was 0.8 mgd (peak tourist season). Average yearly flow estimated to be 0.5 mgd.

TABLE 3. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE COULD OCCUR (Continued)

Plant No.	Flow		Present		Potential		Reduction				Plant Type - Comments
	Actual mgd*	Design mgd	BOD mg/l	TSS mg/l	BOD mg/l	TSS mg/l	BOD lb/day**	BOD ton/yr***	TSS lb/day	TSS ton/yr	
014	1.0****	2.0	22	32	10	10	100	18	183	33	Activated sludge, conventional, without primary clarifiers and with polishing pond. Inadequate process understanding and control caused excessive solids loss. In addition, there was not a pond bypass to discharge good clarifier effluent when the pond effluent was poor.
019	0.035	0.065	57	53	10	10	14	2.5	13	2.3	Activated sludge, conventional, without primary clarifier and with polishing pond. Insufficient sludge wasting and inadequate process understanding, testing, and control caused incomplete organic removal. In addition, there was not a pond bypass to discharge good clarifier effluent when the pond effluent was poor.
020	.007	.025	47	62	10	10	2.2	0.4	3.0	0.5	Activated sludge, extended aeration, without primary clarifiers, and with polishing pond. Insufficient sludge wasting and inadequate process control caused excess solids loss. In addition, there was not a pond bypass to discharge good clarifier effluent when the pond effluent was poor.
027	5.5	10	27	20	10	10	780	142	459	84	Activated sludge, conventional, with anaerobic digesters. Plant effluent periodically violates minimum permit standards, including 85% removal requirement. Inadequate process understanding and control causes incomplete organic removal.

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)
**** Flow during survey was 1.43 mgd (high tourist season). Average yearly flow estimated to be 1.0 mgd.

TABLE 3. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE COULD OCCUR (Continued)

Plant No.	Flow		Present		Potential		Reduction				Plant Type - Comments
	Actual mgd*	Design mgd	BOD mg/l	TSS mg/l	BOD mg/l	TSS mg/l	BOD lb/day**	BOD ton/yr***	TSS lb/day	TSS ton/yr	
028	0.15	0.25	29	10	10	10	24	4.3	0	0	Activated sludge, contact-stabilization, with polishing pond. Inadequate sludge wasting procedure (sludge wasted to pond) caused excessive sludge accumulation in pond and anaerobic decomposition to occur in the pond. The pond was covered with "duckweed" and had no sunlight penetration. As such, soluble BOD_5 in pond effluent was very high and TSS was low. There was not a pond bypass to discharge good clarifier effluent when the pond effluent was poor.
034	5.5	8	50	48	40	40	459	84	367	67	Trickling filter with anaerobic digestion. Inadequate control over flow splitting exercised, which causes imbalanced unit loadings. Also, improper anaerobic digester operation causes excessive solids in supernatant recycle stream, which, again, is not adequately split and causes imbalanced unit loadings.
039	0.21	0.41	44	78	10	10	60	11	119	22	Activated sludge, oxidation ditch, with aerated polishing pond. Insufficient sludge wasting and inadequate process control causes excessive solids loss. There was a pond bypass at this plant.
041	0.13	.40	25	25	20	20	5.4	1.0	5.4	1.0	Two-stage trickling filter, with anaerobic digesters. Slight plant design modification to change recirculation inlet piping location to a point away from the final clarifier weirs would improve final clarifier solids capture capability. It should be noted that no anaerobic digester supernatant is recycled back through the plant.

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)

TABLE 3. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE COULD OCCUR (Continued)

Plant No.	Flow: Actual mgd*	Flow: Design mgd	Present: BOD mg/l	Present: TSS mg/l	Potential: BOD mg/l	Potential: TSS mg/l	Reduction: BOD lb/day**	Reduction: BOD ton/yr***	Reduction: TSS lb/day	Reduction: TSS ton/yr	Plant Type - Comments
047	0.050	0.063	36	76	10	10	11	2.0	28	5.0	Activated sludge, extended aeration, with polishing pond. Insufficient sludge wasting and inadequate process control causes excessive solids loss. In addition, there was not a pond bypass to discharge good clarifier effluent when the pond effluent was poor.
055	0.30	0.58	13	23	10	10	7.5	1.4	33	5.9	Activated sludge, extended aeration, with primary clarifiers and anaerobic digester. Inadequate process control caused periodic slight solids loss. As a general rule, standards have been met.
TOTAL	21.953	35.463	N/A	N/A	N/A	N/A	2401.1	437.5	2065.4	377.2	

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)

TABLE 4. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE IS DOUBTFUL

Plant No.	Flow		Present		Potential		Reduction				Plant Type - Comments
	Actual mgd*	Design mgd	BOD mg/l	TSS mg/l	BOD mg/l	TSS mg/l	BOD lb/day**	BOD ton/yr***	TSS lb/day	TSS ton/yr	
015	1.7	3.6	30	30	Same		-	-	-	-	Two-stage trickling filter with anaerobic digesters. Inherent design features in the plant cause good performance. Plant treats heavy industrial waste and achieves about 96% to 98% removal. Also, anaerobic digester supernatant is not recycled back to the plant, which helps performance significantly. Even so, standards are not met consistently.
021	0.59	0.9	4	7	Same		-	-	-	-	Activated sludge, oxidation ditch, without primary clarifiers. Some good design features in plant cause good performance to be possible. At the same time, good operation overcoming shortcomings in the design of sludge handling and, in addition, adequate process [illegible] performance to be achieved.
024	4.9	6.0	45	31	Same		-	-			[illegible] chlorine oxidized sludge [illegible] capacity causes insufficient [illegible] of BOD_5 to TSS.
026	0.15	0.5	4	4	Same		-	-	-	-	Activated sludge, extended aeration, without primary clarifiers and with tertiary filters. Plant produces good effluent nearly all the time. However, periodically, once to twice per year, for short time periods, raw sewage is bypassed because bulking sludge clogs the filters or because of plant mechanical problems. Individual plant units cannot be bypassed. The flow must pass through the entire plant or be bypassed.

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)

TABLE 4. PLANTS FOR WHICH AN IMPROVEMENT IN PERFORMANCE IS DOUBTFUL (Continued)

Plant No.	Flow		Present		Potential		BOD		TSS		Plant Type - Comments
	Actual mgd*	Design mgd	BOD mg/l	TSS mg/l	BOD mg/l	TSS mg/l	lb/day**	ton/yr***	lb/day	ton/yr	
032	0.22	0.5	30	30	Same		-	-	-	-	Trickling filter with anaerobic "cold" digester. Inherent design features cause plant to perform satisfactorily with minimum operation. Summer performance was good as measured during survey. Historical performance questionable because monitoring records were believed inaccurate. Winter performance believed to be poor because City was going to enter into a 201 Facilities plan for plant upgrade.
035	5.3	5.4	22	20	Same		-	-	-	-	Two-stage trickling filter with anaerobic digester. Conservative design features and good operation cause plant to perform as well as expected.
036	1.6	2.8	22	21	Same		-	-	-	-	Two-stage trickling filter with anaerobic digester. Conservative design features and good operation cause plant to perform as well as expected.
040	0.38	0.63	56	29	Same		-	-	-	-	Rotating biological surface with anaerobic digesters. Inadequate aeration capability limits conversion of BOD_5 to TSS.
063	0.7	1.5	7	10	Same		-	-	-	-	Activated sludge, extended aeration, without primary clarifiers. Plant can bypass flow it cannot handle to a larger facility. Plant saves money when it accepts more sewage because treated water is used for parks and golf course watering. At least 1.5 mgd can be adequately treated by the existing facility. Inadequate process control causes limited treatment capacity. However, because plant can accept less flow, standards are consistently met.
TOTAL	15.54	21.83	N/A	N/A	-		-	-	-	-	

* mgd x 3785 = cu m/day
** lb x .453 = kg
*** ton x 0.906 = metric ton (1000 kg)

achieved and likely exceeded if CCP's were implemented at these facilities. It was recognized that many of the facilities in Table 3 for which improved performance could be expected would require minor plant modifications as part of a CCP. These minor modifications were differentiated from major facility expansions in that they could be completed by plant personnel and/or a local contractor and would not justify extensive planning ("201" studies), design, and construction steps normally associated with plant upgrades. An example minor modification would be adding the piping flexibility to discharge a good quality mechanical plant effluent when desired, rather than having to discharge a poor quality polishing pond effluent.

Various approaches were used to develop performance data for Tables 2 and 3. Whenever possible, accurate records were used to indicate performance. However, at some plants the historical data did not reflect known poor performance conditions, especially in plants which had a history of "bulking" sludge. (Note: "Bulking" as used here does not differentiate between a true poor settling sludge and an excess solids inventory condition). At plants which had good sludge wasting records, the amount of solids lost due to bulking was estimated by determining the amount of activated sludge wasted after operations assistance was provided and the excessive solids loss condition was eliminated and comparing this value with the amount of sludge wasted prior to assistance. In these plants an increase or decrease in the system's sludge inventory was considered in determining solids loss due to bulking. At plants with poor sludge wasting records an empirical sludge production value was calculated based on plant loading and design information. Using these methods, the amount of TSS lost in the effluent was estimated. Typically, the amount of BOD_5 lost during bulking periods was less than the amount of TSS lost. During evaluations at five plants, separate samples were collected during observed bulking periods. These samples were analyzed for BOD_5 and TSS concentration. The average BOD_5 to TSS ratio for these samples was 0.5. Therefore, for plants with a history of sludge bulking, the effluent BOD_5 concentrations were calculated to be 50 percent of the estimated TSS concentrations, unless records were available to obtain more specific BOD_5 values.

In plants with effluent polishing ponds, historical data for BOD_5 and TSS removals through the ponds was usually not available. In many of these facilities the mechanical plant performance was poor and had been poor, as evidenced by a large sludge accummulation in the ponds. In this respect, the ponds had been instrumental in removing some of the solids discharged in the mechanical plant effluent. However, none of these facilities consistently met standards. Two major points are made with respect to mechanical plants followed by polishing ponds. One point is that some pollutant removal occurs within ponds. The extent of the removal is seasonal in nature and is dependent upon pond detention time, but nevertheless occurs. A second point is that the addition of polishing ponds did not allow any of the facilities investigated to consistently meet secondary treatment standards. A polishing pond was not a satisfactory substitute for good plant operation. Pond bypasses allowing direct discharge of a high quality mechanical plant effluent were recommended in conjunction with improved operation at facilities that had polishing ponds. The addition of pond bypasses was considered a minor plant modification in establishing the values presented for the potential performance of plants with effluent polishing ponds.

The actual and estimated potential improvement in plant performance from Tables 2 and 3 are summarized in Table 5. Overall total improvement is also shown. This total improvement could be achieved if CCP's, excluding major facility expansion, were implemented at all twenty-one of the facilities shown in Tables 2 and 3. The projected total reduction of BOD_5 discharged is 490 metric tons/year (540 tons/yr), and the total reduction of TSS discharged is 470 metric tons/year (516 tons/yr). This represents a reduction in the mass of BOD_5 and TSS presently discharged of 37.7 percent and 36.9 percent, respectively.

During the evaluation of improved performance, it was recognized that significant differences in existing and potential effluent quality existed between two major facility categories: suspended growth and fixed film. The suspended growth category was comprised of activated sludge facilities and included twenty of the thirty facilities evaluated. The fixed film category was comprised of trickling filter, rotating biological contractor and activated bio-filter facilities, and included ten of the thirty facilities evaluated. The existing and potential performances from Tables 2, 3 and 4 for each category are summarized in Table 6.

TABLE 5. PROJECTED IMPROVED PERFORMANCE USING CCP'S WITHOUT MAJOR FACILITY EXPANSIONS

	Improved Performance Occurred	Improved Performance Potential	Total Improved Performance
No. of Plants	7	14	21
Effluent BOD_5			
Total lb/day*	558	2401	2959
Total ton/year**	102	438	540
Effluent TSS			
Total lb/day*	765	2065	2830
Total ton/year**	139	377	516

* kg/day = lb/day x 0.453

**Metric tons/year = tons/year x 0.906

The existing performance of the suspended growth and fixed film facilities was nearly the same for BOD_5. The mean (not weighted average) effluent BOD_5 concentration was 34 mg/l for the suspended growth facilities and 37 mg/l for the fixed film facilities. The mean effluent TSS concentration was significantly greater for the suspended growth facilities at 52 mg/l, as opposed to 31 mg/l for the fixed film facilities.

Also shown in Table 6 are the high effluent BOD_5 and TSS concentrations for each facility category. These high concentrations represent the poorest effluent quality for a given facility within each of the two categories, as documented in Tables 2, 3 and 4. The poorest effluent quality for a suspended growth facility was 68 mg/l for BOD_5 and 117 mg/l for TSS, while the poorest effluent quality for a fixed film system was lower at 56 mg/l for BOD_5 and 48 mg/l for TSS. Although some suspended growth facilities are performing considerably poorer than the fixed film facilities, the potential performance for suspended growth facilities through CCP's is significantly better than

TABLE 6. EXISTING AND POTENTIAL PERFORMANCE FOR SUSPENDED GROWTH AND FIXED FILM FACILITIES SURVEYED

		Suspended Growth	Fixed Film
No. of Facilities		20	10
Total Flow - mgd*		11.8	29.2
Size Range - mgd*		0.007 - 5.5	0.13 - 8.1
Existing Performance			
Effluent BOD_5 - mg/l	(Mean)	34	37
	(High)	68	56
Effluent TSS - mg/l	(Mean)	52	31
	(High)	117	48
Potential Performance After CCP's			
Effluent BOD_5 - mg/l	(Mean)	9.2	33
	(High)	10	56
Effluent TSS - mg/l	(Mean)	9.6	28
	(High)	10	40
Potential Improvement Through CCP's			
Additional BOD_5 Removed			
ton/year (total)**		324	215
lb/mg***		150	40
Percent Improvement		66	13
Additional TSS Removed			
ton/year (total)**		378	137
lb/mg***		175	26
Percent Improvement		68	10

* mgd x 3785 = cu m/day

** tons/year x 0.906 = metric tons/year

*** lb/mg x 0.120 = gm/cu m

for fixed film facilities. The mean potential effluent BOD_5 and TSS concentrations for the suspended growth facilities were 9 mg/l and 10 mg/l, respectively. The mean potential effluent BOD_5 and TSS concentrations for the fixed film facilities were 33 mg/l and 28 mg/l, respectively, which is near secondary treatment standards.

In both suspended growth and fixed film facilities, an improvement in effluent quality can be achieved through CCP's without major facility upgrades. The potential reduction in BOD_5 and TSS for the suspended growth facilities was 294 metric tons per year (324 tons/year) and 342 metric tons per year (378 tons/year), respectively. The potential reduction in BOD_5 and TSS for the fixed film facilities was 195 metric tons per year (215 tons/year) and 124 metric tons per year (137 tons/year), respectively. The total potential improvement in performance for the suspended growth facilities was slightly greater than for the fixed film facilities, but was significantly greater per unit of wastewater flow. The combined wastewater flow rate for the suspended growth facilities was 44,800 cu m/day (11.8 mgd) compared to 110,600 cu m/day (29.2 mgd) for the fixed film facilities. The resulting potential reduction per unit of wastewater flow was significantly greater for the suspended growth facilities at 18 gm/cu m (150 lb/mg) for BOD_5 and 21 gm/cu m (175 lb/mg) for TSS, compared to 4.8 gm/cu m (40 lb/mg) for BOD_5 and 3.1 gm/cu m (26 lb/mg) for TSS for the fixed film facilities.

The fixed film facilities surveyed exhibited poor performance that cannot be satisfactorily improved through CCP's which exclude major plant modifications. Major plant modifications are required to expand the unit size of the secondary treatment process (i.e., implement a more conservative design). The potential reductions in pollutant discharge for fixed film facilities with CCP's that exclude major modifications were only about 13 and 10 percent of the existing discharge for BOD_5 and TSS, respectively. The suspended growth facilities exhibited poorer performance than fixed film facilities, but their performance can be improved significantly through CCP's that exclude major modification. The potential reductions in pollutant discharge for suspended growth facilities were 65 and 68 percent of the existing discharge for BOD_5 and TSS, respectively. From this evaluation it was concluded that, in general, a more conservative design approach is required for fixed film facilities and better operation is required for suspended growth facilities.

ADDITIONAL FACILITIES ABLE TO MEET SECONDARY TREATMENT STANDARDS

Most of the thirty facilities surveyed were constructed before the present secondary treatment standards were promulgated, but all were designed to provide secondary treatment. A few facilities were required to meet more stringent standards. For this report, all facilities were analyzed with respect to their ability to meet the minimum monthly secondary treatment standard of 30 mg/l for BOD_5 and TSS. The results are presented in Table 7. It should be noted that the division of plants in Table 7 does not correspond to the division of plants in Tables 2, 3 and 4, since some plants' performance could be improved with a CCP but would still not meet secondary treatment standards. Also, at some plants that met secondary standards the performance could be further improved with a CCP.

TABLE 7. SUMMARY OF PERFORMANCE OF THIRTY PLANTS SURVEYED VERSUS MINIMUM SECONDARY TREATMENT STANDARDS

	Prior to Preliminary Survey	After Preliminary Survey	Potential
Number of plants where standards were consistently met	7	13	23
Number of plants where standards were frequently violated	23	17	7

Prior to the research evaluations only seven facilities were meeting secondary treatment standards consistently. After the evaluations, which included some operations assistance, an additional six facilities, for a total of thirteen, met standards. Ten more facilities, for a total of twenty-three, have the potential of meeting standards through implementation of CCP's without major facility modifications. The remaining seven of the thirty facilities would require major plant modifications before they would consistently meet secondary standards.

Three of the seven facilities meeting secondary treatment standards prior to the research evaluation were considered to have both good design and good operation. Two of the remaining four facilities were underloaded (50 percent and 35 percent of design hydraulic loading) and were meeting secondary treatment requirements, but could have performed better. Another was able to consistently meet secondary treatment standards because of the ability to bypass part of the influent wastewater flow to a larger facility. This facility would satisfactorily treat a greater wastewater flow by improving plant operations. The fourth facility performed well when operating, but required total shut-down and bypassing of raw sewage during periods of bulking sludge and/or mechanical breakdown. Bypassing did not occur during the evaluation, but the facility was operating at only 30 percent of its design hydraulic loading. As loading to the plant increases more bypassing can be expected. Major modifications will be required to correct the problems at this facility.

ADVANTAGE OF A COMPOSITE CORRECTION PROGRAM

Composite Correction Programs can achieve dramatic improvements in wastewater treatment facility performance. However, CCP's have typically not been used to improve performance at existing facilities that violate secondary treatment standards. The typical approach has been to complete major plant modifications, usually through the federal construction grant process. This approach was used at two facilities studied as a part of this research effort which were violating their permit standards. Just prior to the research evaluations, major plant modifications were completed which doubled the plant capacities. During the research evaluations, neither facility was meeting its permit standard. The original deficiencies that were limiting performance were not addressed in the plant upgrades. Further, it was judged that if these deficiencies were corrected before the plants had been expanded, the expansions <u>would not have been required</u>. The deficiencies that existed prior to the plant expansions and continued to exist after the expansions still needed to be corrected before satisfactory performance could be achieved. A properly conducted CCP at these two plants could have satisfactorily improved their performance and eliminated the need for expansion. The greatest cost advantage for CCP's occurs when they eliminate the need for a major facility modification. For these cases, cost savings through CCP's could reach several hundred thousand dollars per plant.

Exact costs for a typical CCP are difficult to estimate for a variety of reasons. A CCP always includes the cost of providing the technical assistance service and may contain costs necessary for minor plant modifications, staffing additions, spare parts additions, increased sludge handling, etc. The cost of a CCP is dependent upon facility size and type and the number and magnitude of factors limiting the plant's performance. Because each facility is unique in its specific collection of performance limiting factors, the cost for each CCP would be widely varied. A cost for an 1890 to 18900 cu m/day (0.5 to 5 mgd) activated sludge plant would typically range from $5,000 to $50,000. The general approach to conducting every CCP is similar and is described in this section of the report. The approach described for conducting CCP's is relative to the size range of plants evaluated during this research effort (i.e., less than 37,850 cu m/day (10 mgd).

Implementation of a CCP involves technical assistance time for an initial on-site visit, telephone consultations and follow-up on-site visits. The overall time period for which the CCP is conducted is typically one year. The relative time involvement for implementing a CCP is illustrated in Figure 6. Time for on-site visits, telephone consultation, and the overall time period during which the CCP is conducted varies depending upon facility size and type, plant personnel training, plant personnel attitude and aptitude and other performance limiting factors that exist at the facility. As such, the initial on-site visit may require a few days up to several weeks. This initial visit is followed with "waiting time" and telephone consultation. Telephone consultation with the plant process control coordinator may be maintained on a daily, semi-weekly or weekly basis, depending upon the situation. The waiting time and telephone consultation activities are interspersed with on-site visits during which problems are investigated further and technical assistance activities and training are reinforced. The follow-up on-site

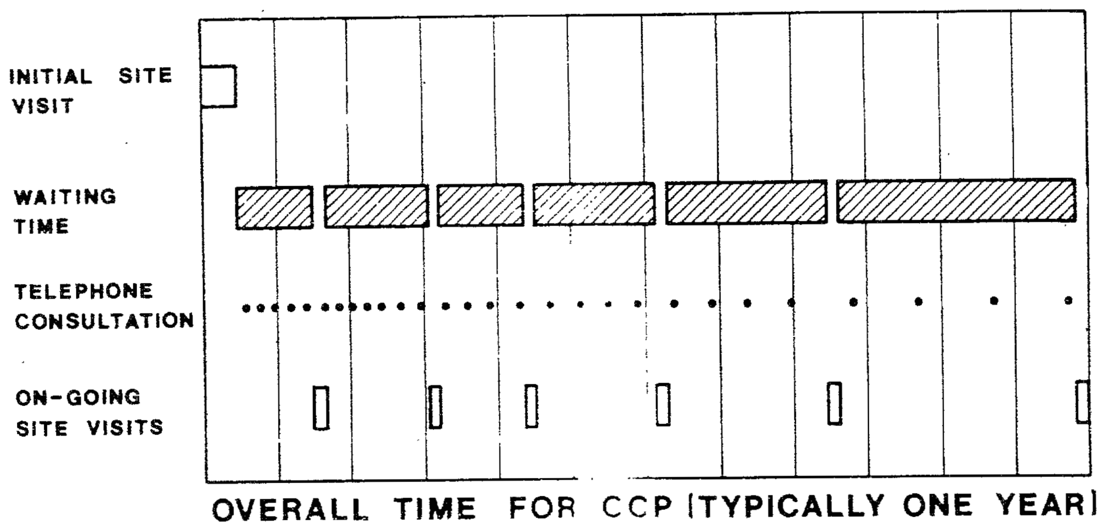

Figure 6. Relative time involvement for CCP activities.

visits are scheduled at weekly, bi-weekly, monthly or bi-monthly intervals depending on the need. Each on-site visit typically lasts from one to five days.

The outlined approach for implementing a CCP has numerous advantages for achieving and maintaining desired facility performance. The long time involvement greatly increases the chances of identifying and correcting problems in the administration, maintenance and design areas. Also, the long time frame is very compatible with optimizing a biological system which has an inherently slow responsive nature. Another advantage is that during the time optimum facility performance is being achieved, process control capability is transferred to plant personnel so they can maintain performance at the improved levels. This transfer is accomplished by interspersing on-site, one-on-one training activities and telephone consultation activities with waiting time. During the waiting time plant personnel are forced to observe changes in biological system characteristics and complete the required process control adjustments. Plant personnel must then discuss their observations and adjustments with the technical assistant. This procedure of "guided observance" of system response is a very effective mechanism to develop the operator's ability to correctly apply concepts of plant operation to process control. Also, the technical assistant is better prepared to conduct other CCP's due to the experience gained by accounting for process response over a long period of time. These advantages are further accentuated by the fact that plant and administrative personnel gain long term access to technical guidance at a minimal cost. Judicious use of waiting time allows the cost for CCP's to be minimized relative to the long time involvement benefits gained.

Presently, plant upgrading through construction is usually selected as the alternative for improving the performance at a plant that is violating its permit standards. Some level of plant modification or upgrade might be considered adequate to enable facilities to meet standards with a minimum emphasis on plant operation. However, twenty-three of the thirty facilities evaluated (6) did not meet secondary treatment standards, yet the average hydraulic loading of these plants was only 61 percent of design. The average loading for the seven plants which met standards was not much lower at 55 percent of design capacity. Plants which met secondary standards were loaded as high as 98 percent of design. It was concluded that plant over design alone did not significantly promote good performance. However, a CCP conducted in conjunction with or prior to plant expansion does identify and correct problems at existing plants and may eliminate the need for a plant expansion at some facilities. In this context, the cost comparison of a CCP versus plant upgrading through construction is irrelevant. Plant upgrading to achieve better performance cannot be a substitute for a CCP, but rather should only occur as a part of a CCP.

REFERENCES

1. "Clean Water Report to Congress - 1973, 1974, 1975 Annual Reports", U.S. Environmental Protection Agency, Washington, D.C., May 1973, June 1974, June 1975.

2. "Continuing Need for Improved Operation and Maintenance of Municipal Waste Treatment Plants", Report to the Congress by the Comptroller General of the United States, Washington D.C., (April 11, 1977).

3. Perry, Robert R., "WPCF Role in Improving O & M", Journal of Water Pollution Control Federation, 49, 1635 (1977).

4. Milstone, M.L., "Operations Personnel: They Go Where the Money Is", Journal of Water Pollution Control Federation, 49, 1949 (1977).

5. Gilbert, Walter G., "Relation of Operation and Maintenance to Treatment Plant Efficiency", Journal of Water Pollution Control Federation, 48, 1822 (1976).

6. Hegg, B.A., K.L. Rakness, and J.R. Schultz, "Evaluation of Operation and Maintenance Factors Limiting Municipal Wastewater Treatment Plant Performance", report prepared in partial fulfillment of EPA Contract No. 68-03-2224, U.S. Environmental Protection Agency, Cincinnati, Ohio, (1978).

7. Hegg, B.A., "Procedures Used in Conducting Selected Activated Sludge Control Tests", M & I, Inc., Consulting Engineers, Fort Collins, Colorado (October 1973).

8. West, A.W., "Operational Control Procedures for the Activated Sludge Process", EPA-330/9-74-001-6, U.S. Environmental Progection Agency, Cincinnati, Ohio (April, 1973).

9. Ahlberg, N.R., and B.I. Boyko, "Evaluation and Design of Aerobic Digesters", Journal of Water Pollution Control Federation, 44, 634 (1972).